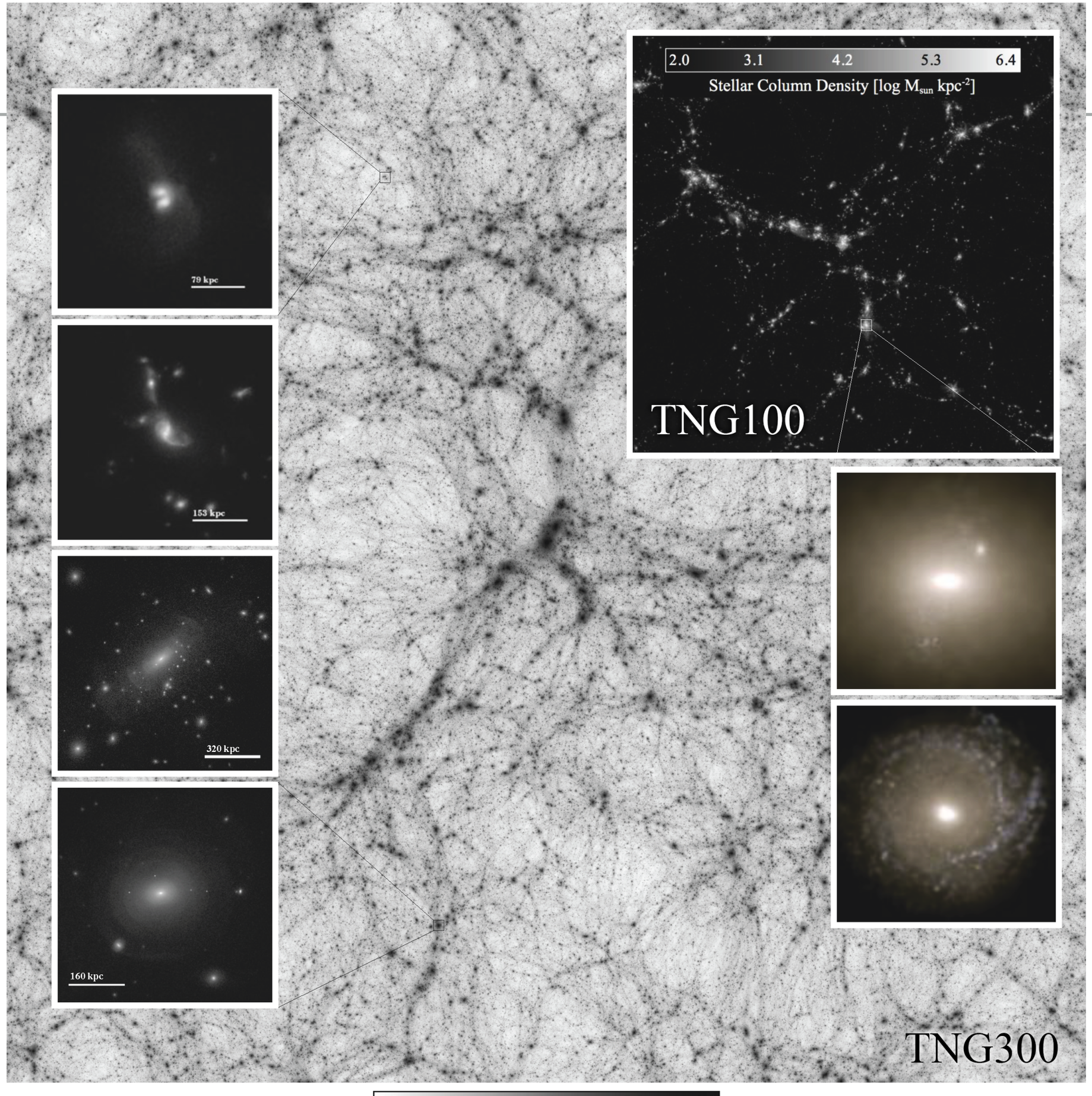
Jingjing Shi 史晶晶 arXiv:2104.12329

(with Ken Osato, Toshiki Kurita, and Masahiro Takada)

# AN OPTIMAL ESTIMATOR OF INTRINSIC ALIGNMENTS FOR STAR-FORMING GALAXIES

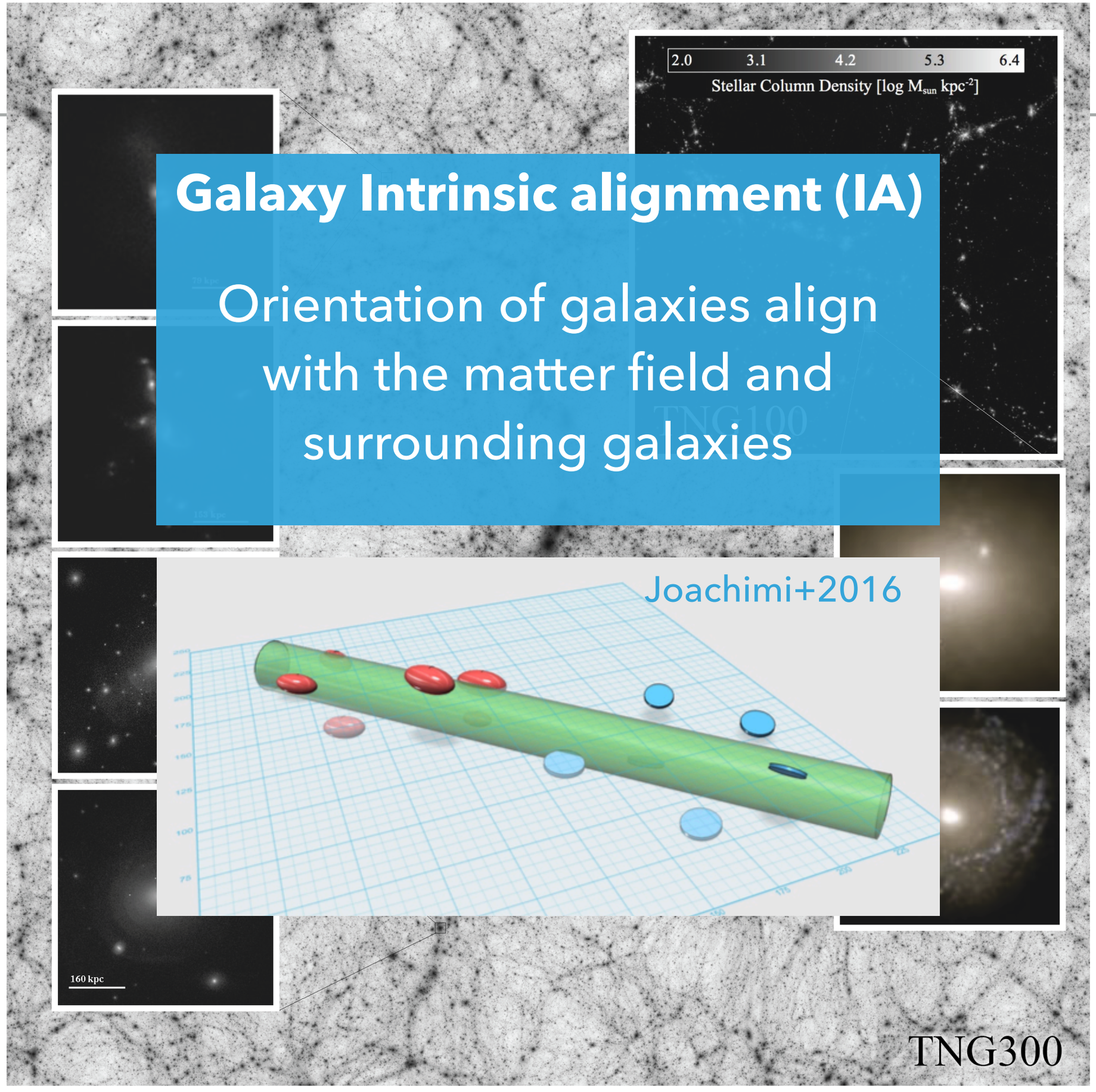



5.5 6.2 6.8 7.5 8.2
Dark Matter Column Density [log $M_{sun}$ kpc$^{-2}$]

https://www.tng-project.org

# Galaxy Intrinsic alignment (IA)

Orientation of galaxies align with the matter field and surrounding galaxies



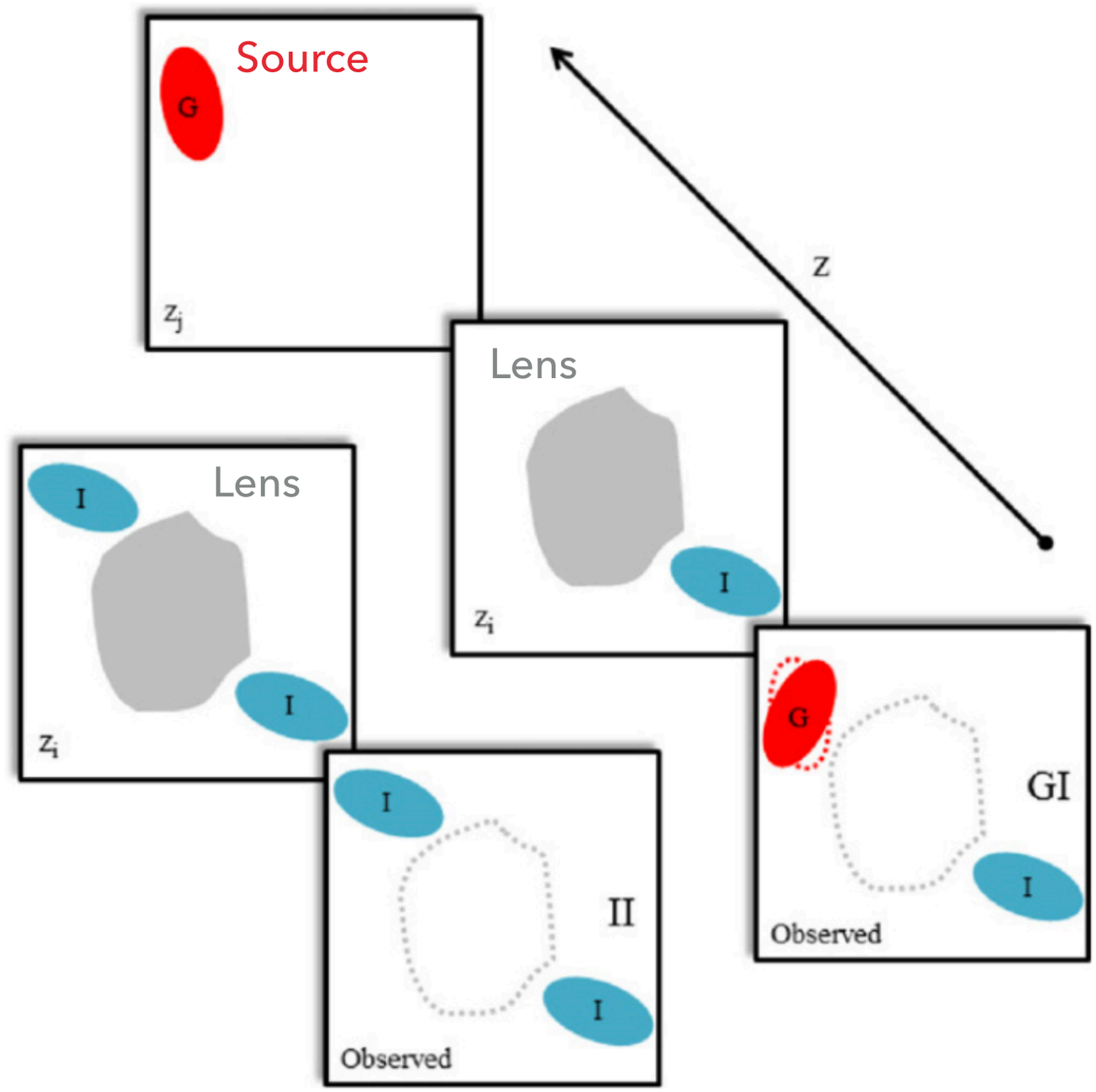

https://www.tng-project.org

5.5 6.2 6.8 7.5 8.2
Dark Matter Column Density [log $M_{sun}$ kpc$^{-2}$]

# INTRINSIC ALIGNMENT – WHY IMPORTANT



- Contaminates Weak Lensing Cosmology (Hirata & Seljak 2004, Troxel+2015)

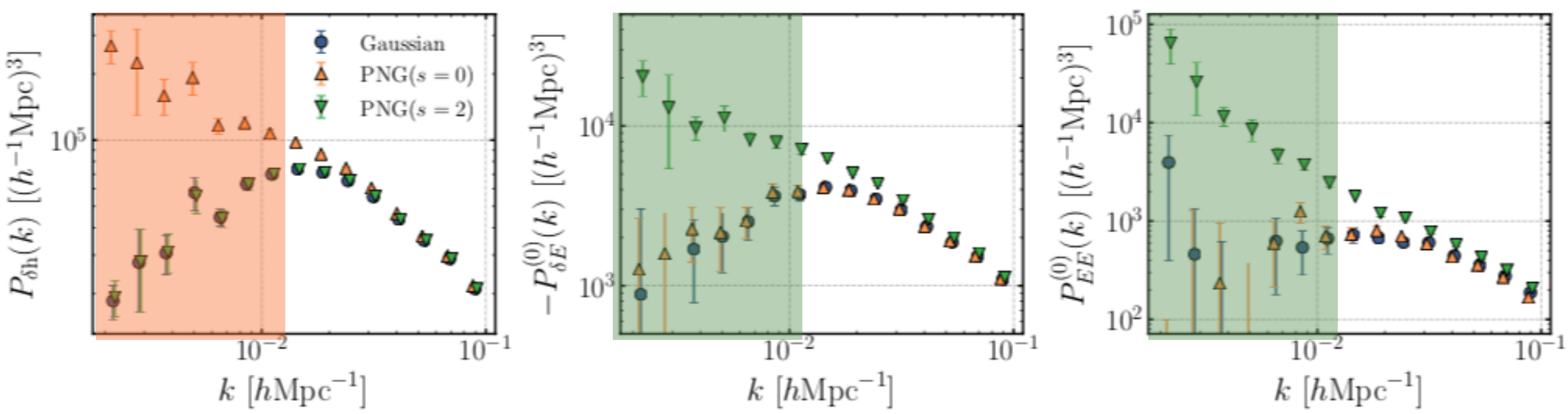


# INTRINSIC ALIGNMENT – WHY IMPORTANT



- Contaminates Weak Lensing Cosmology (Hirata & Seljak 2004, Troxel+2015)
- Probe of cosmology: Primodial non-Gaussianity, BAO (Chisari+2013, Chisari+2016, Akitsu+2020)
- Constrains galaxy formation and evolution

IA –> sensitive probe of anisotropic PNG (s=2)



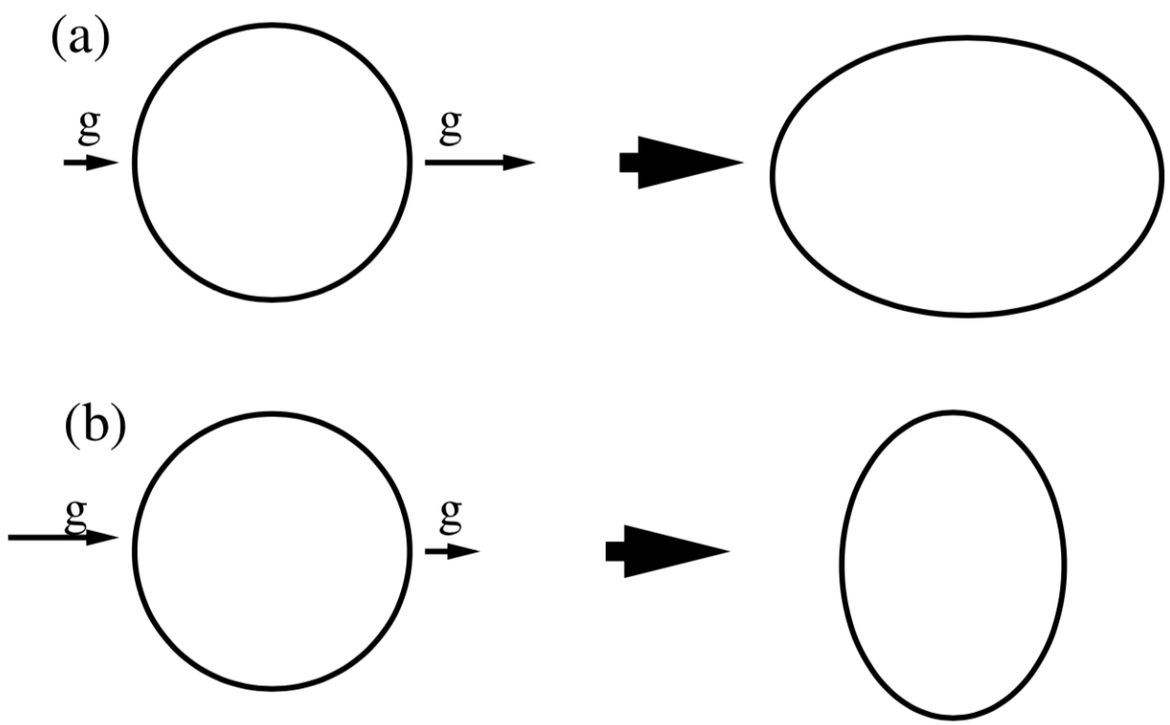

Akitsu+2020

Clustering –> isotropic PNG (s=0)

Dalal+2008

# TIDAL ALIGNMENT MODEL






tidal field
↓
elongate/compress the halo

**Linear alignment model**

Intrinsic shear

$$\gamma^I = -\frac{C_1}{4\pi G}(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y)\mathcal{S}[\Psi_P]$$

Primordial potential

$$\Psi_P(\mathbf{k}) = -4\pi G\frac{\bar{\rho}(z)}{\bar{D}(z)}a^2k^{-2}\delta_{lin}(\mathbf{k}),$$

Cross correlation of intrinsic shear and matter field

$$P_{\delta,\tilde{\gamma}^I}(k) = -\frac{C_1\bar{\rho}}{\bar{D}}a^2P_\delta^{lin}(k).$$

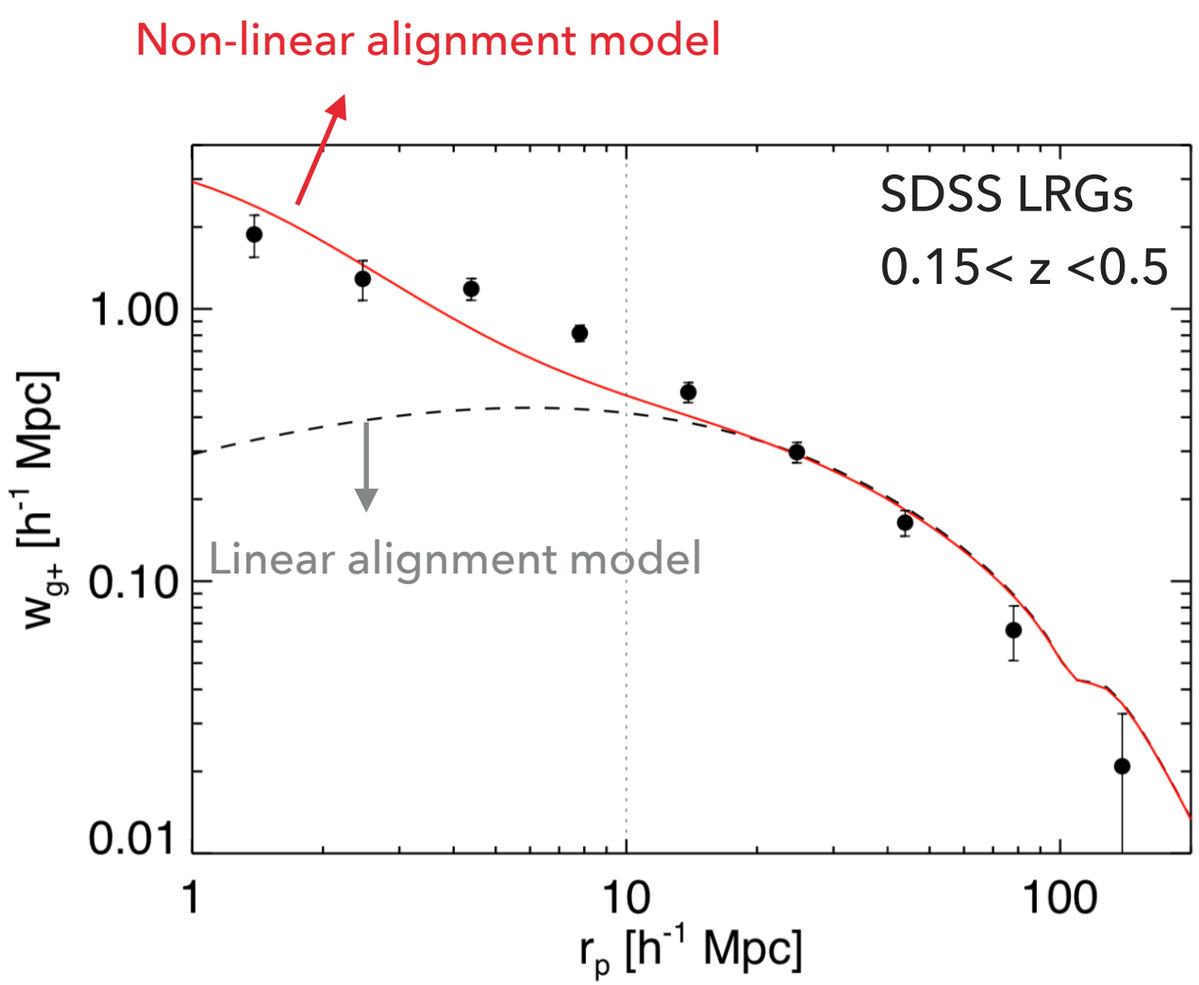
**Non-linear alignment model**

replace linear power spectrum by its non-linear one

Catelan+2001, Hirata & Seljak 2004, Bridle & King 2007

# INTRINSIC ALIGNMENT – OBSERVATIONS



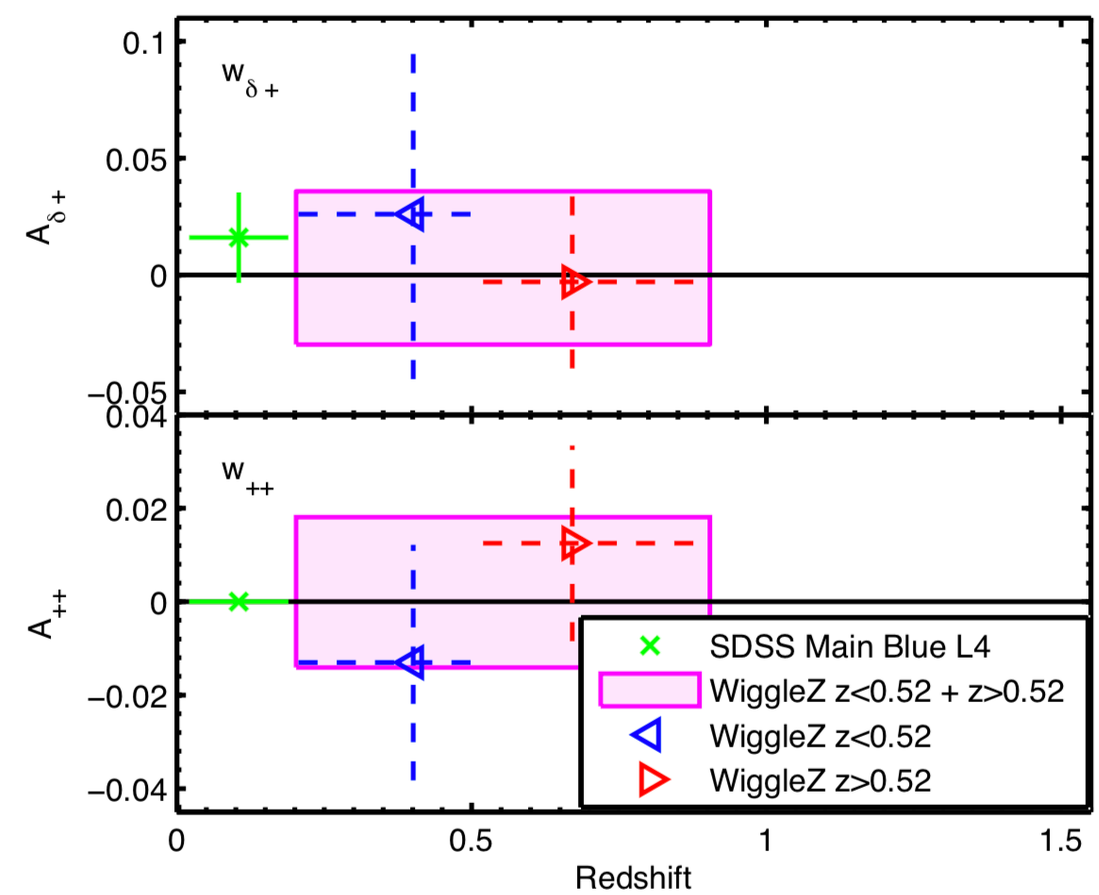



LRGs – clear IA signal shown by the correlation function between galaxy positions and intrinsic ellipticities

Okumura & Jing 2009, Blazek+2011

Mandelbaum+2011, Yao+2020

Blue star-forming galaxies – no clear IA signal detected so far



# ELGS SURVEYS



Prime Focus Spectrograph
SuMIRe

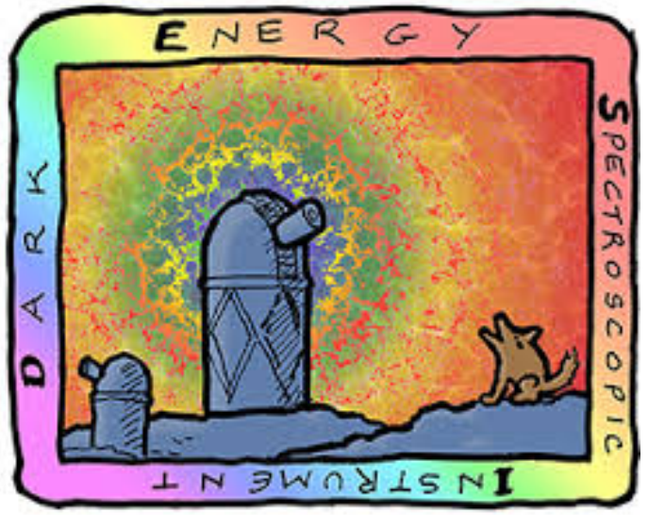
| | Testing ΛCDM | Assembly history of galaxies | Importance of IGM |
|---|---|---|---|
| CO | • Nature & role of neutrinos<br>• Expansion rate via BAO up to $z$=2.4<br>• PFS+HSC tests of GR | • PFS+HSC synergy<br>• Absorption probes with PFS/SDSS QSOs around PFS/HSC host galaxies | • Search for emission from stacked spectra |
| GA | • Curvature of space: $\Omega_K$<br>• Primordial power spectrum<br>• Nature of DM (dSphs) | • Stellar kinematics and chemical abundances – MW & M31 assembly history | • dSph as relic probe of reionization feedback<br>• Past massive star IMF from element abundances |
| GE | • Structure of MW dark halo<br>• Small-scale tests of structure growth | • Halo-galaxy connection: $M_*/M_{\rm halo}$<br>• Outflows & inflows of gas<br>• Environment-dependent evolution | • Physics of cosmic reionization via LAEs & 21cm studies<br>• Tomography of gas & DM |

**PFS survey cosmology:** use single tracer ([OII] emission line galaxies, i.e. ELGs) to map evolution of the large-scale structure of the Universe in a wide range of redshifts, 0.6 < z < 2.4, over 1400 deg$^2$ sky area covered also by the HSC image survey

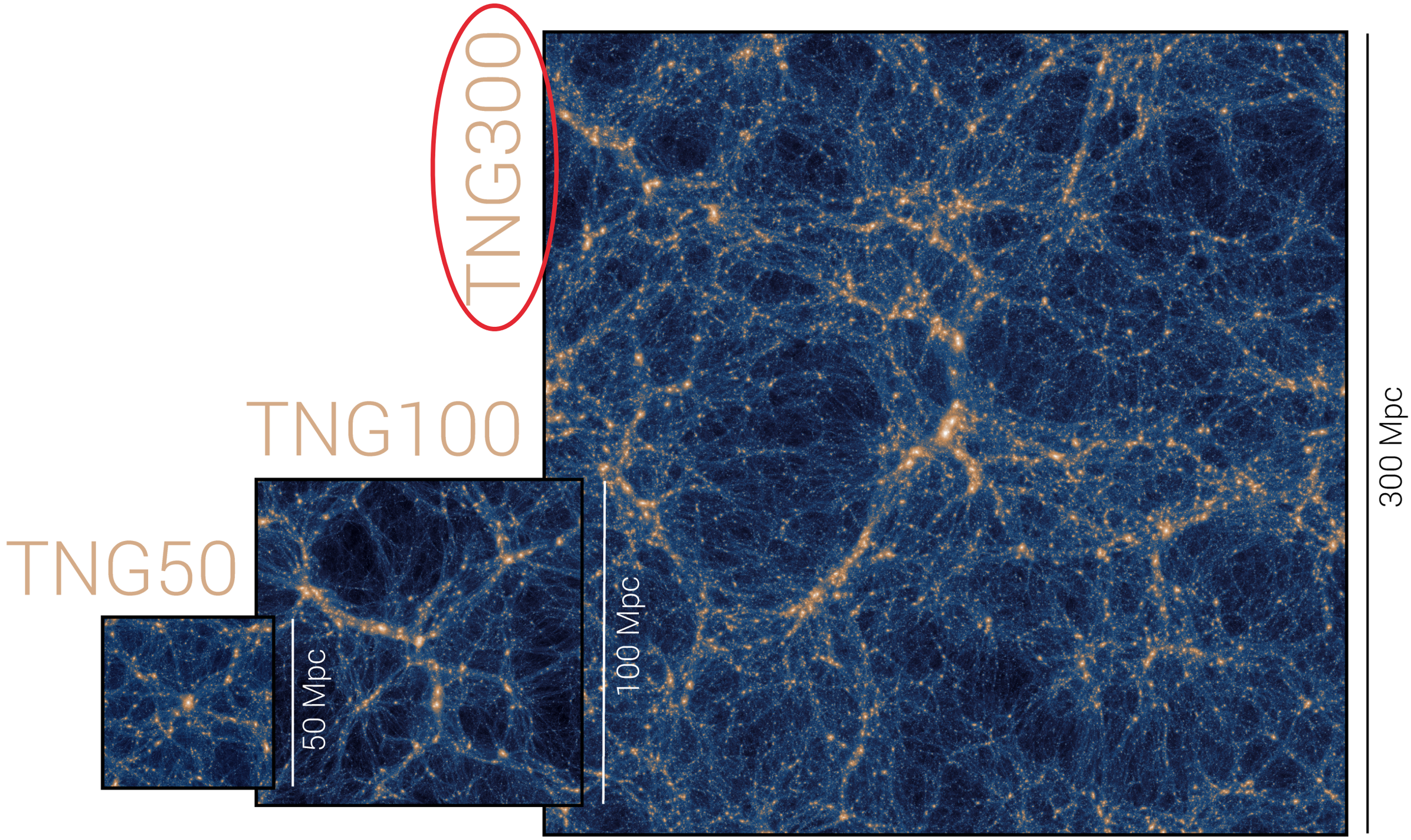
**DESI targets:**

| Galaxy type | Redshift range | Bands used | Targets per deg$^2$ | Exposures per deg$^2$ | Good $z$'s per deg$^2$ | Baseline sample |
|---|---|---|---|---|---|---|
| LRG | 0.4–1.0 | $r$,$z$,$W1$ | 350 | 580 | 285 | 4.0 M |
| ELG | 0.6–1.6 | $g$,$r$,$z$ | 2400 | 1870 | 1220 | 17.1 M |
| QSO (tracers) | $< 2.1$ | $g$,$r$,$z$,$W1$,$W2$ | 170 | 170 | 120 | 1.7 M |
| QSO (Ly-$\alpha$) | $> 2.1$ | $g$,$r$,$z$,$W1$,$W2$ | 90 | 250 | 50 | 0.7 M |
| **Total in dark time** | | | **3010** | **2870** | **1675** | **23.6 M** |
| BGS | 0.05–0.4 | $r$ | 700 | 700 | 700 | 9.8 M |
| **Total in bright time** | | | **700** | **700** | **700** | **9.8 M** |

DESI Collaboration, 2016



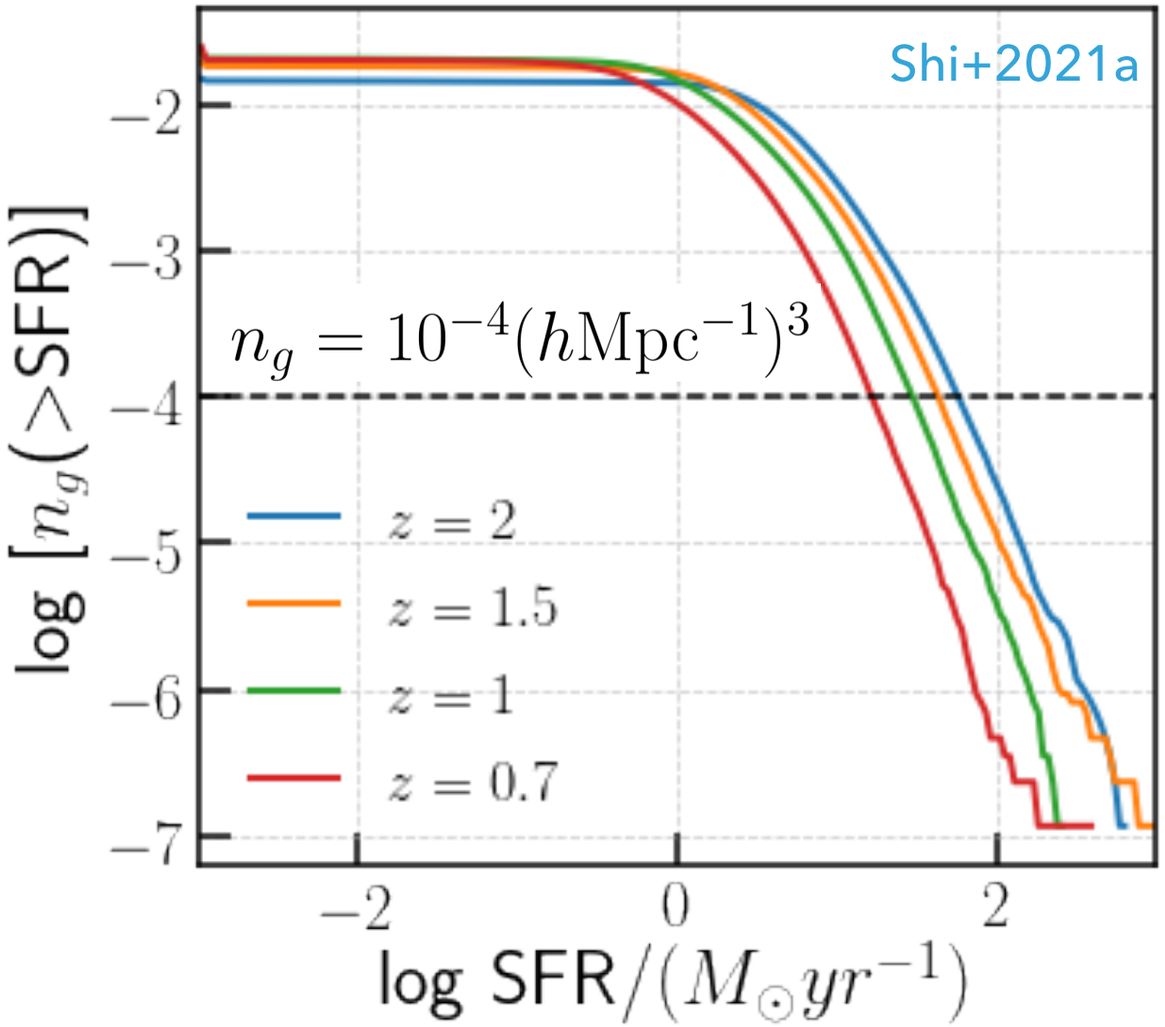
**? Is there an estimator that optimally extracts the IA signal surrounding the star-forming galaxies (i.e. ELGs)**




https://www.tng-project.org

# SELECTION OF ELGS IN TNG300






**SFR ranked selected** galaxies

*roughly corresponds to*

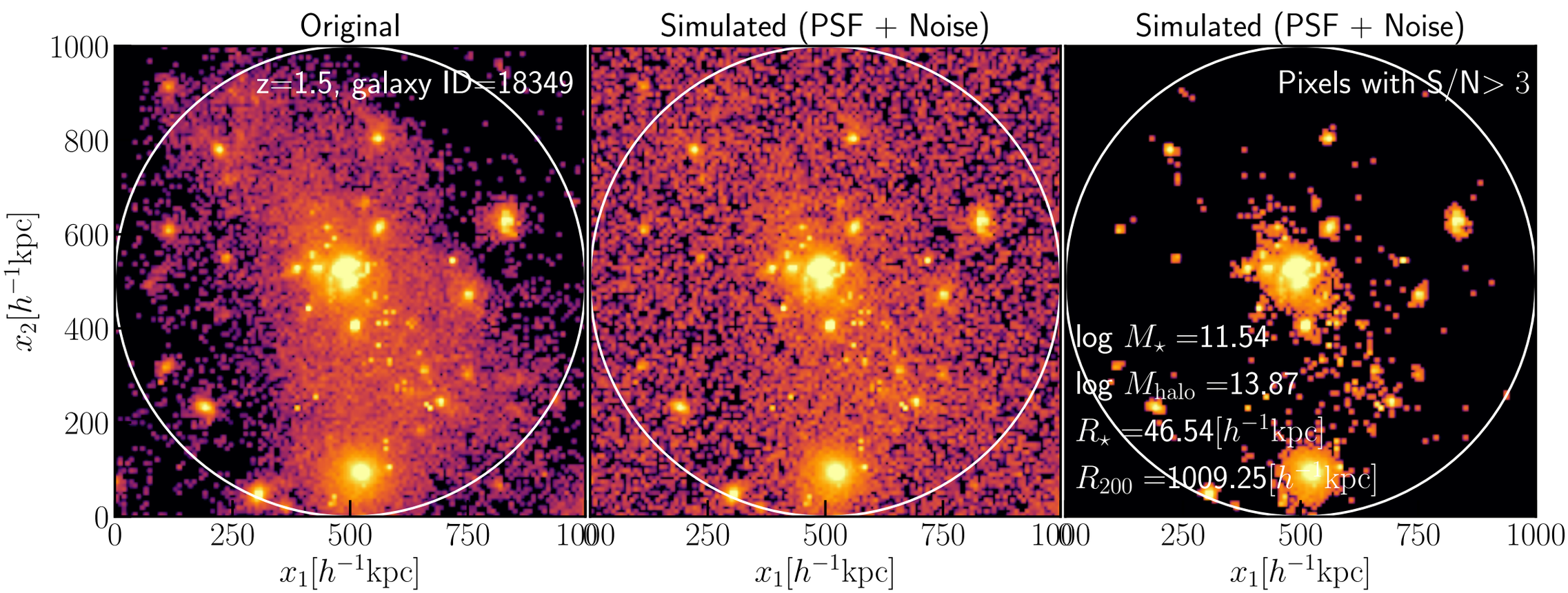
**[OII] emission line strength** selected galaxies

Gonzalez-Perez+2020; Osato & Okumura 2021, in prep

| $z$ | $\langle \log M_\star \rangle$ | $\langle \log M_{\mathrm{halo}} \rangle$ | $\langle \mathrm{SFR} \rangle$ | $f_{\mathrm{cen}}$ |
|---|---|---|---|---|
| 0.5 | 11.39 | 13.20 | 3.59 | 0.899 |
| 1.0 | 11.25 | 13.04 | 6.00 | 0.894 |
| 1.5 | 11.13 | 12.88 | 6.29 | 0.895 |
| 2.0 | 11.04 | 12.67 | 10.48 | 0.886 |

Shi+2021b

# Ray-tracing simulation using Pégase.3 code

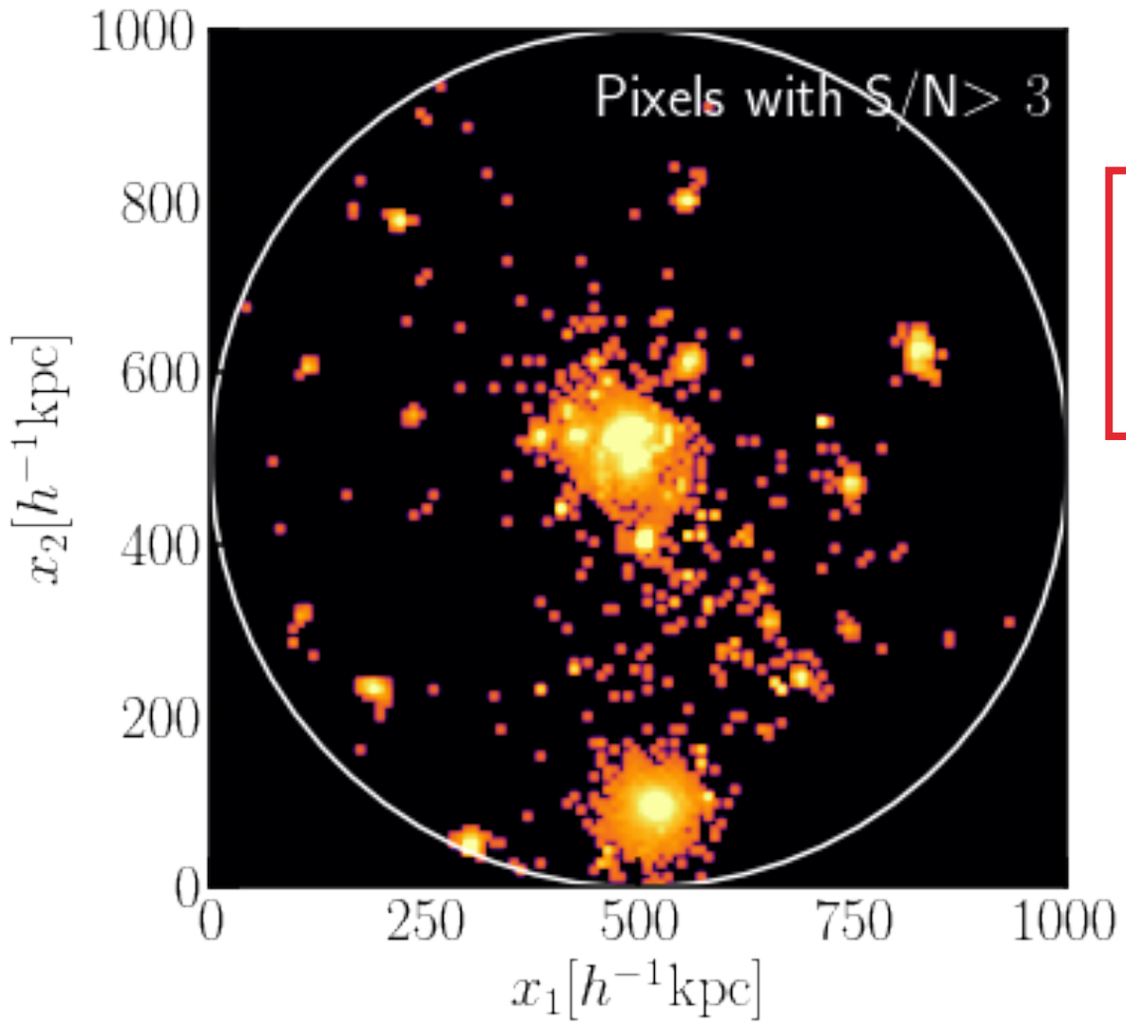



0.6 arcsec seeing
1200sec exposure
8.2m Subaru aperture

Shi+2021b

# APERTURE SHAPE ESTIMATOR






Shi+2021b

$$I_{ij}^{\mathrm{ap}} = \frac{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n x_{ni} x_{nj}}{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n}$$

$f_n$ -- flux of pixels

$x_{ni}, x_{nj}$ -- distance of pixels to the ELG

**1Mpc/h aperture** *versus* **within ELG**

**no weighting** *versus* **1/r² weighting**

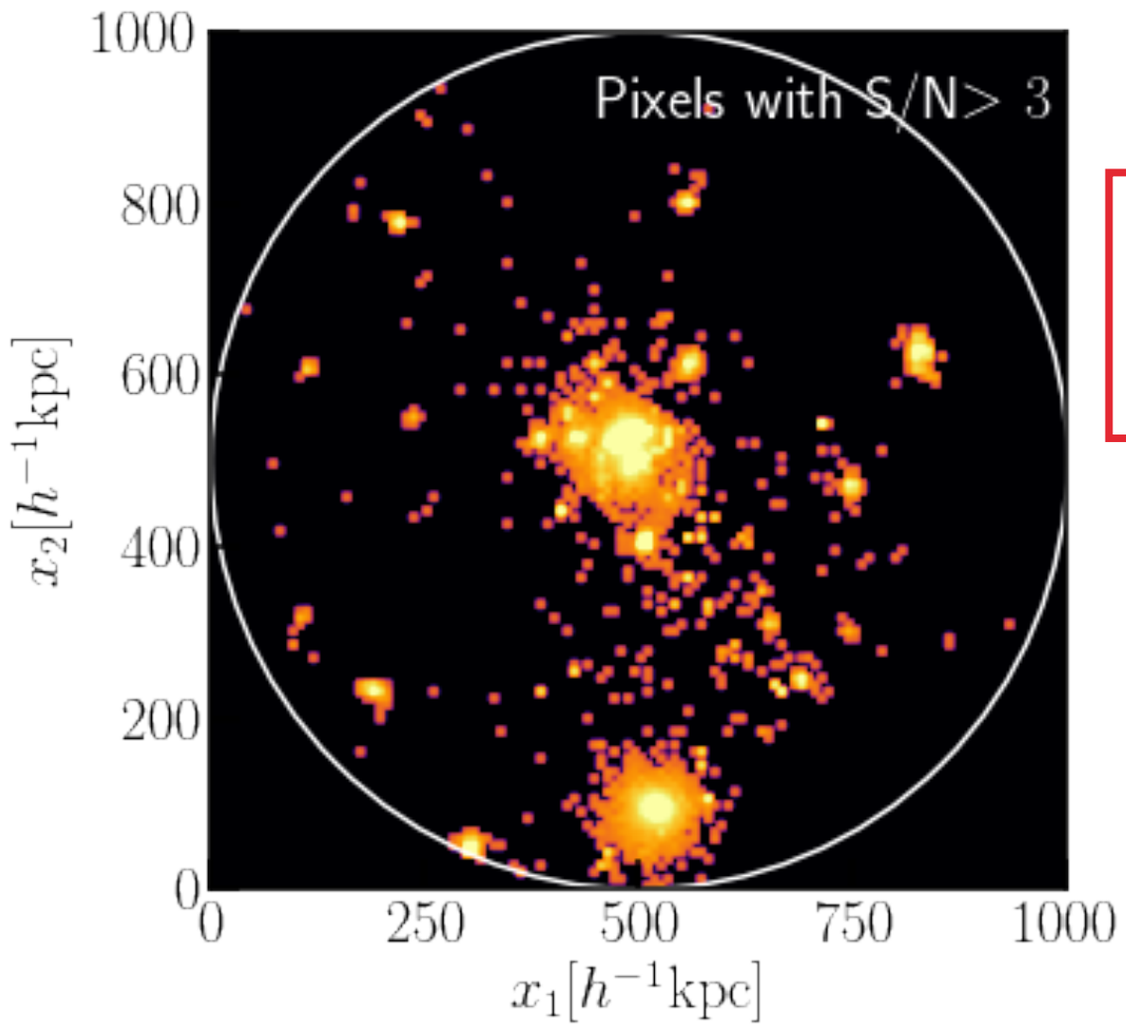
## Reduced inertia tensor

$$I_{ij}^{\mathrm{reduced}} = \frac{\sum_n m_n \frac{x_{ni} x_{nj}}{r_n^2}}{\sum_n m_n}$$

$m_n$ -- mass of the stellar particles within the galaxy

# APERTURE SHAPE ESTIMATOR






Shi+2021b

$$I_{ij}^{\mathrm{ap}} = \frac{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n x_{ni} x_{nj}}{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n}$$

$f_n$ -- flux of pixels

$x_{ni}, x_{nj}$ -- distance of pixels to the ELG

$$\epsilon_1 \equiv \frac{I_{11} - I_{22}}{I_{11} + I_{22}}, \epsilon_2 \equiv \frac{2I_{12}}{I_{11} + I_{22}}$$

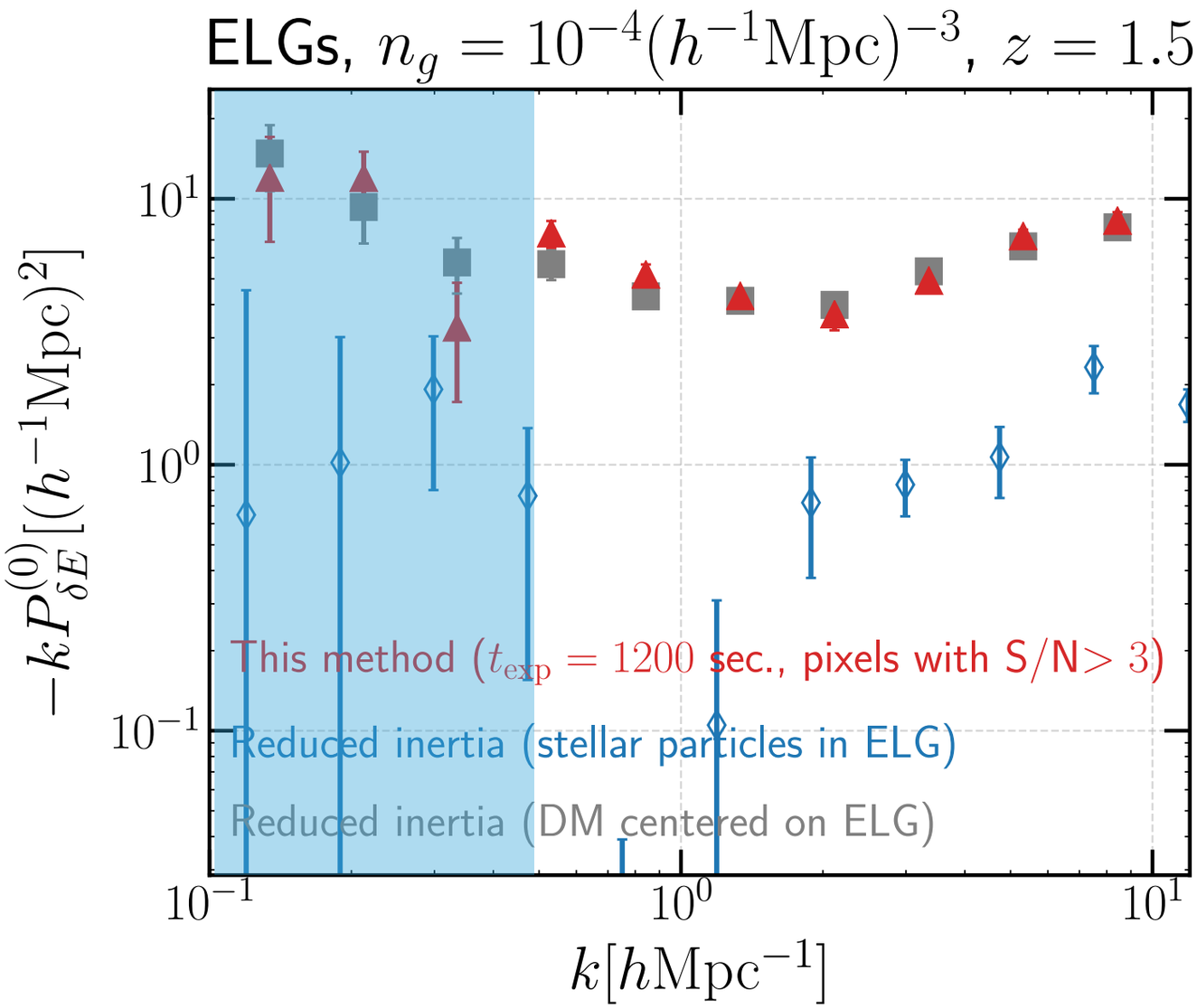
**Reduced inertia tensor**

$$I_{ij}^{\mathrm{reduced}} = \frac{\sum_n m_n \frac{x_{ni} x_{nj}}{r_n^2}}{\sum_n m_n}$$

$m_n$ -- mass of the stellar particles within the galaxy

# IA OF ELGS





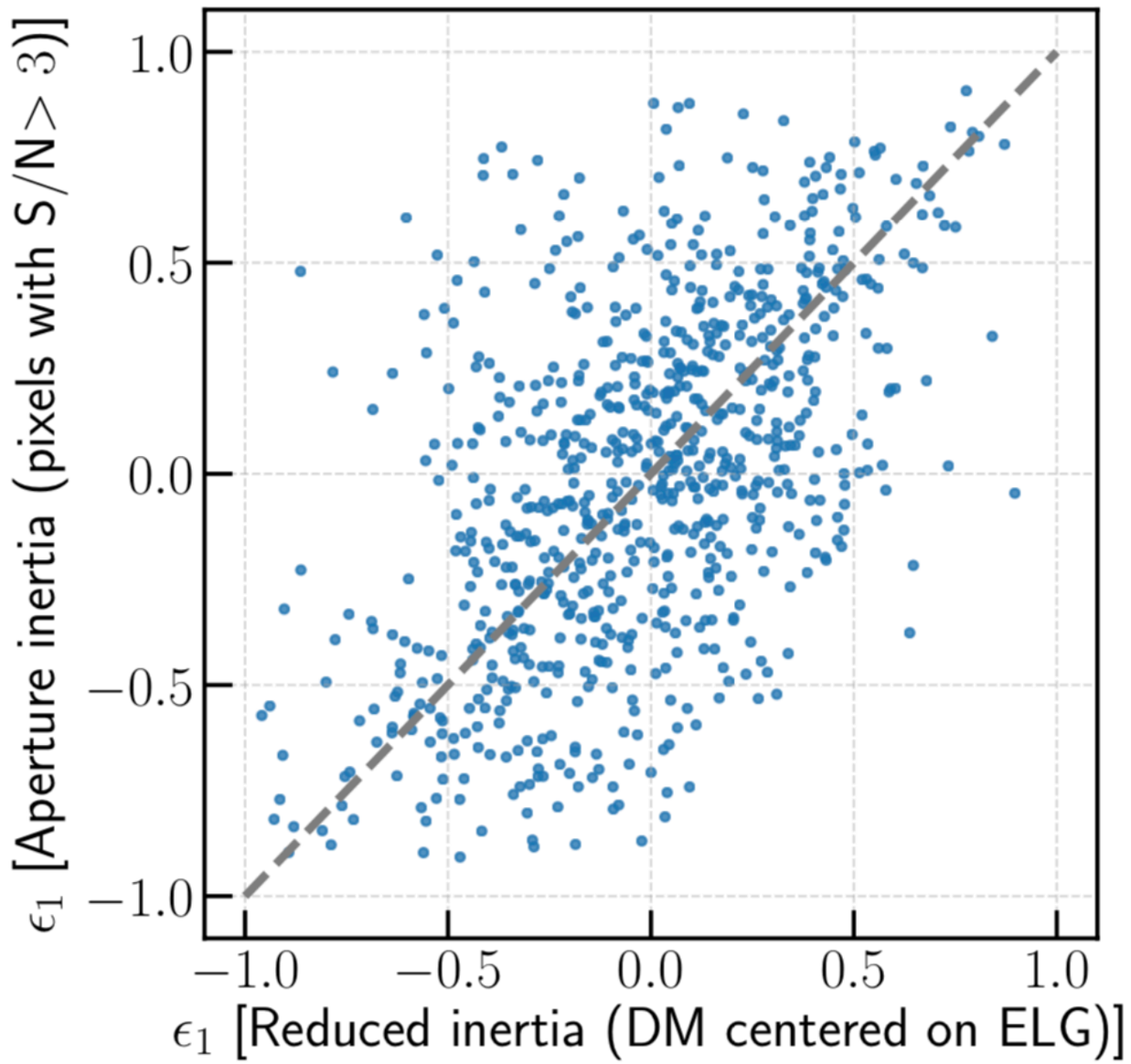

Shi+2021b

**Aperture shape estimator**
***captures***
**the IA signal surrounding the ELGs**

$$\langle \gamma_E(\boldsymbol{k})\delta_m(\boldsymbol{k'})\rangle \equiv (2\pi)^3\delta_D(\boldsymbol{k}+\boldsymbol{k'})P_{\delta E}(\boldsymbol{k})$$

→ IA power spectrum
(Kurita+2020, Shi+2021a)

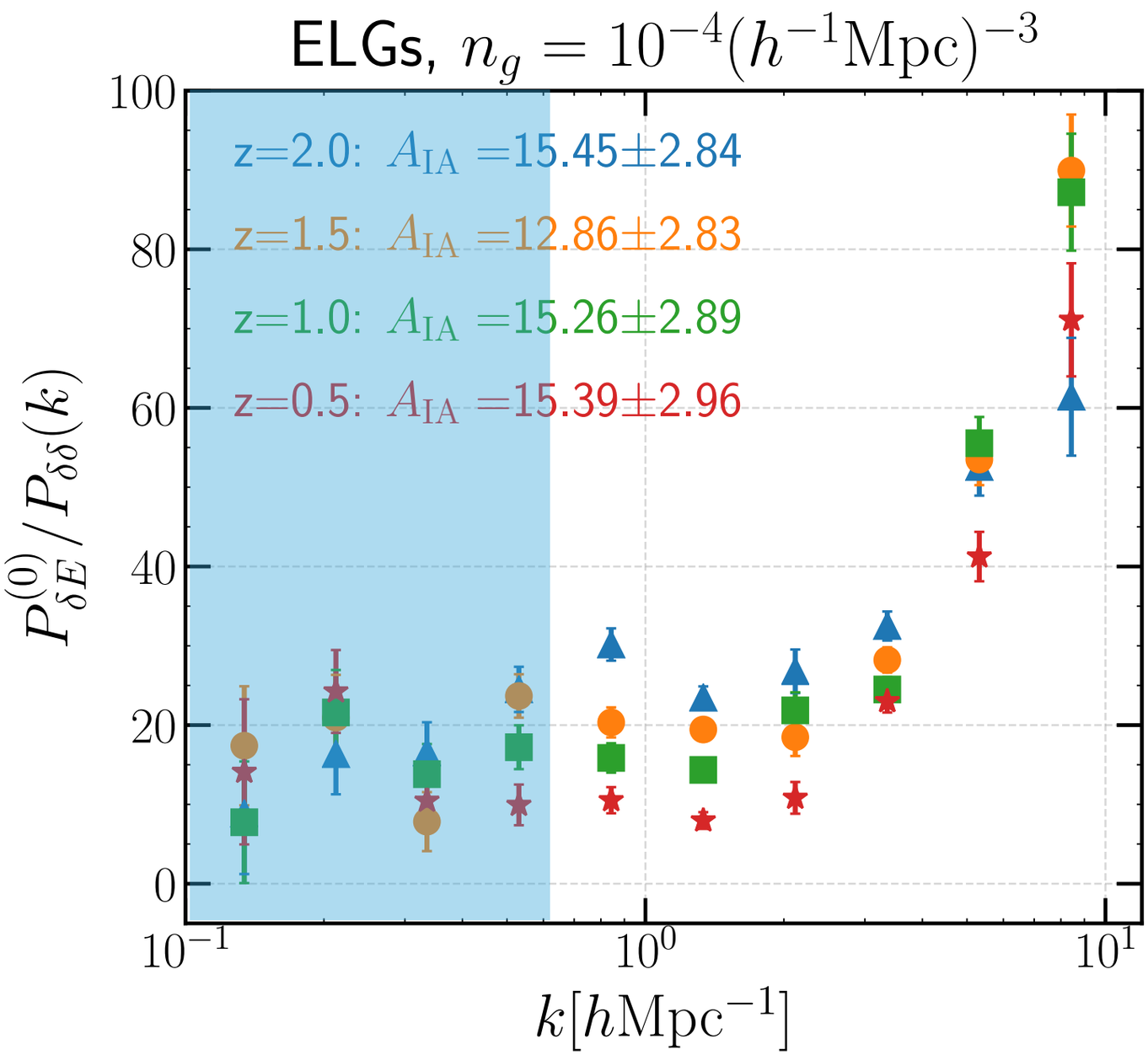
# ELLIPTICITIES OF ELGS




Light distribution follows the matter distribution

# REDSHIFT EVOLUTION






Shi+2021b

**Non-linear alignment model**

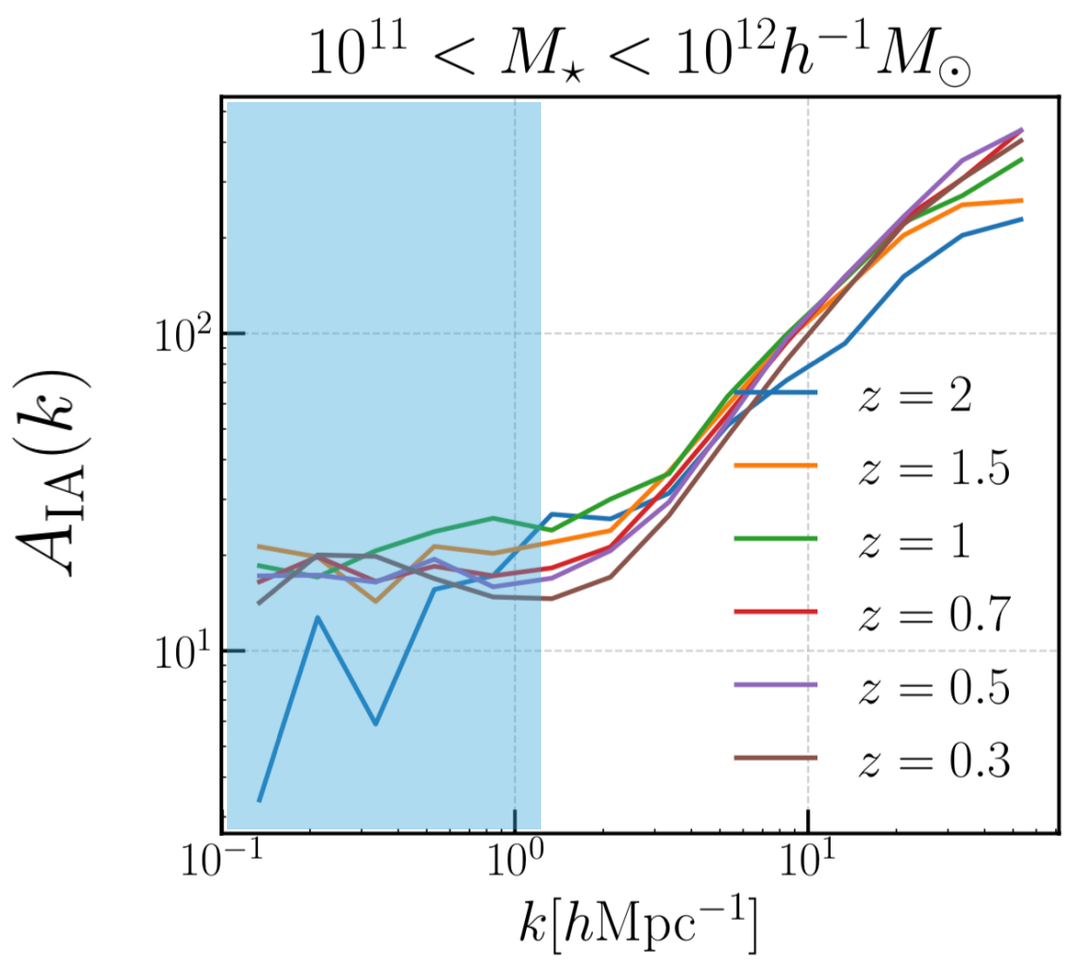
$$P_{\delta E}(k,\mu) = -A_{\rm IA} C_1 \rho_{\rm cr0} \frac{\Omega_{\rm m}}{D(z)} (1-\mu^2) P_{\delta\delta}(k,z)$$

# REDSHIFT EVOLUTION



Shi+2021b

| $z$ | $\langle \log M_\star \rangle$ | $\langle \log M_{\rm halo} \rangle$ | $\langle {\rm SFR} \rangle$ | $f_{\rm cen}$ | $A_{\rm IA}$ | $\sigma_\epsilon$ |
|---|---|---|---|---|---|---|
| 0.5 | 11.39 | 13.20 | 3.59 | 0.899 | $15.39 \pm 2.96$ | 0.43 |
| 1.0 | 11.25 | 13.04 | 6.00 | 0.894 | $15.26 \pm 2.89$ | 0.41 |
| 1.5 | 11.13 | 12.88 | 6.29 | 0.895 | $12.86 \pm 2.83$ | 0.39 |
| 2.0 | 11.04 | 12.67 | 10.48 | 0.886 | $15.45 \pm 2.84$ | 0.40 |

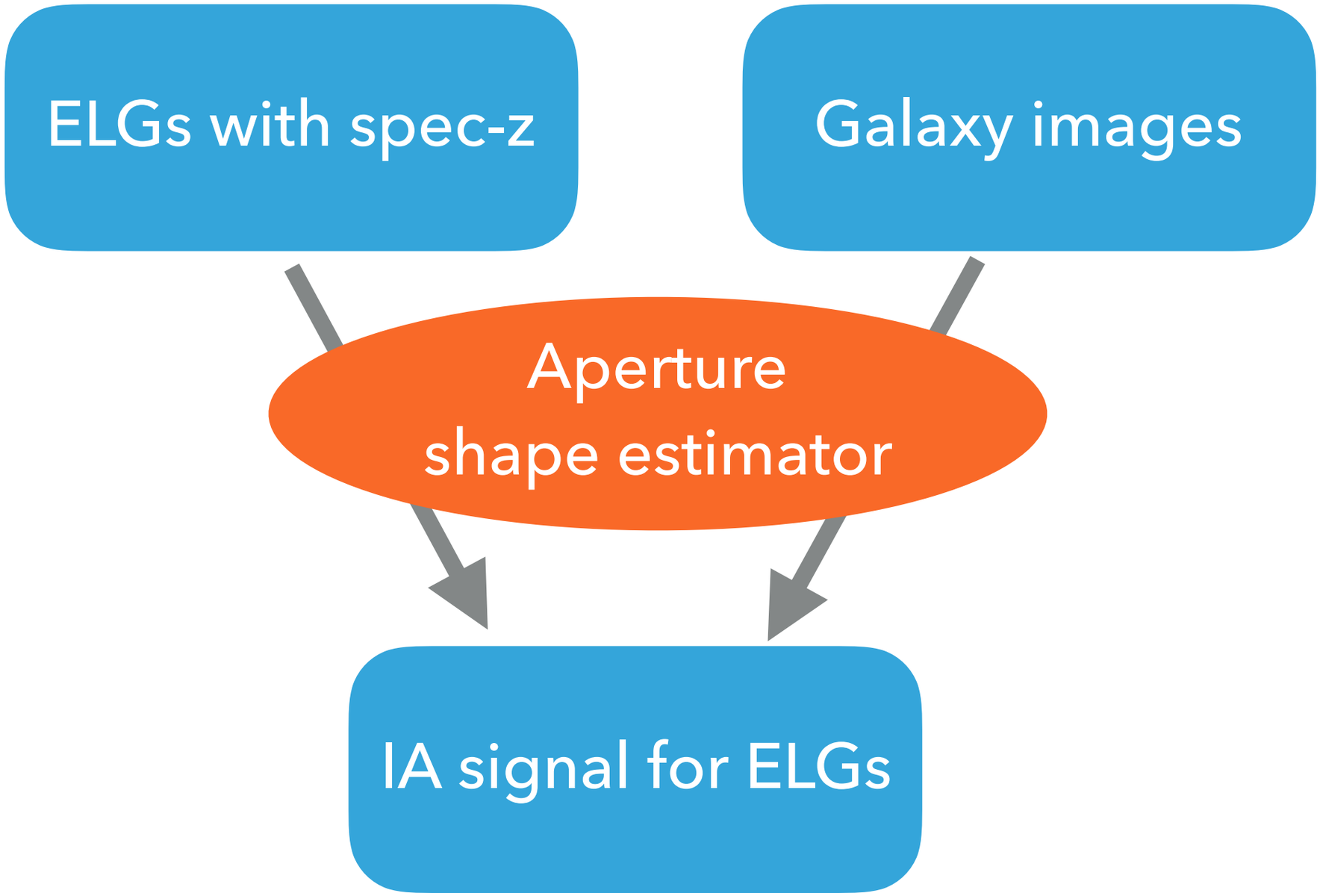



**Given stellar mass, weak/no redshift evolution of galaxy IA**

Shi+2021a

# SUMMARY




ELGs with spec-z
Galaxy images
Aperture
shape estimator
IA signal for ELGs